LCA Methodology

A Life Cycle Impact Assessment Procedure with Resource Groups as Areas of Protection

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Abstract

Goal and Background. Current Life Cycle Impact Assessment (LCIA) procedures have demonstrated certain limitations in the South African manufacturing industry context. The aim of this paper is to propose a modified LCIA procedure, which is based on the protection of resource groups.

Methods. A LCIA framework is introduced that applies the characterisation procedure of available midpoint categories, with the exception of land use. Characterisation factors for land occupation and transformation is suggested for South Africa. A distance-to-target approach is used for the normalisation of midpoint categories, which focuses on the ambient quality and quantity objectives for four resource groups: Air, Water, Land and Mined Abiotic Resources. The quality and quantity objectives are determined for defined South African Life Cycle Assessment (SALCA) Regions and take into account endpoint or damage targets. Following the precautionary approach, a Resource Impact Indicator (RII) is calculated for the resource groups. Subjective weighting values for the resource groups are also proposed, based on survey results from the manufacturing industry sector and the expenditure trends of the South African national government. The subjective weighting values are used to calculate overall Environmental Performance Resource Impact Indicators (EPRIIs) when comparing life cycle systems with each other. The proposed approaches are evaluated with a known wool case study.

Results and Discussion. The calculation of a RII ensures that all natural resources that are important from a South African perspective are duly considered in a LCIA. The results of a LCIA are consequently not reliant on a detailed Life Cycle Inventory (LCI) and the number of midpoint categories that converge on a single resource group. The case study establishes the importance of region-specificity, for LCIs and LCIAs.

Conclusions. The proposed LCIA procedure demonstrates reasonable ease of communication of LCIA results. It further allows for the inclusion of additional midpoint categories and is adaptable for specific regions.

Recommendations and Outlook. The acceptance of the LCIA procedure must be evaluated for different industry and government sectors. Also, the adequate incorporation of Environmental Performance Resource Impact Indicators (EPRIIs) into decision-making for Life Cycle Management purposes must be researched further. Specifically, the application of the procedures for supply chain management will be investigated.

Keywords: Air; areas of protection; environmental performance; land; life cycle management (LCM); life cycle impact assessment (LCIA); mined abiotic resources; modified LCIA procedure; resource groups; South African manufacturing industry; water

1 Introduction

Life Cycle Impact Assessment (LCIA) methodologies have been evaluated and compared in the context of the South African manufacturing industry [1]. The main limitations associated with the evaluated European LCIA methods were identified as:

- Certain impact categories, which are critical from a South African environmental perspective are often omitted in the classification step, e.g. water and land availability.
- The modelling procedures for characterisation factors may not be appropriate for South Africa, e.g. the chemical transformation, and pathway and exposure scenarios for air, water and soil pollutants are most probably dissimilar in South Africa compared to Europe.
- The normalisation factors are typically not applicable to South Africa, i.e. the normalisation values do not reflect the current state of the impact categories with the South African natural environment as a reference system. Furthermore, the current emissions and resource consumption of the South African society is not known for all of the impact categories (of existing LCIA methods) and different normalisation factors must be considered.
- The subjective weighting mechanisms and values are not a good indication of the importance that the South African society places on different environmental categories.

The scope therefore existed to propose a South African specific LCIA procedure within the framework of the United Nations Environmental Programme (UNEP) and Society for Environmental Toxicology and Chemistry (SETAC) global life cycle initiative [2]. Within the South African manufacturing industry context a LCIA procedure should evaluate the impacts equally on four main environmental resource groups, including the sub-groups: Water Resources, Air Resources, Land Resources, Mined Abiotic Resources [1,3]. The South African constitution of 1996 (Act 108) stipulates in Section 24 that the quantity and quality of these natural resources must be maintained for society (human health and welfare) and the ecology in general (ecosystem quality) for present and future generations [4]. Therefore, 'resources' refer to all aspects of the ambient natural environment that must be maintained in order to ensure the sustainability of human health (and welfare) and ecosystems. Furthermore, an evaluation of environmental checklists, sustainable development indicators and environmental performance indicators identified these four resource groups as Areas of Protection (AoP) where industrial projects have potential impacts [5].

A modification to existing LCIA approaches has subsequently been proposed, which focuses on these resource groups or AoP [6]. The aim of this paper is to analyse the Resource Impact Indicators (RIIs) that are calculated from the proposed LCIA framework, with a known screening LCA case study of wool production in South Africa [1].

2 A Life Cycle Impact Assessment (LCIA) Procedure in the South African Context

2.1 South African resource impact indicator (RII) framework

A framework for a LCIA procedure to calculate Resource Impact Indicators (RIIs) for South Africa has been introduced [6], which incorporates and adheres to the requirements for a coherent set of classified environmental categories that have been proposed [7]:

- Exhaustive (completeness); all relevant criteria for the evaluation of manufacturing systems must be included. If a criterion were excluded, the framework would be redundant in theory, although an exhaustive set of criteria may not be practical.
- Cohesion; a singular criterion can determine the preference of a life cycle system or phase of a system.

For the RII framework the environmental categories of the CML methodology [8] are taken with the inclusion of water use as an additional category, and with a modification to the land use characterisation mechanism. The CML procedure has shown the least limitations in the South African context [1], and is also the most up-to-date in the public domain (as at the end of 2002).

The categories that are provisionally considered in the RII framework are shown in **Fig. 1**. However, the exhaustiveness of the categories should be taken into account on a case-by-case basis. As a first approximate, the characterisation factors stipulated in the CML documentation [8] are taken for the categories (except for land and water use), although certain limitations can be expected in the South African context [1].

Fig. 1 shows that LCI constituents (and midpoint categories) may impact more than one sub-resource group, which could lead to double counting [9]. Furthermore, the subsequent optional valuation steps of LCIA [10] should be modified to indicate the extent of impacts on the four main resource groups from a South African perspective. These issues are addressed in the calculation of the RIIs.

2.2 Resource impact indicator (RII) calculation

The calculation of the Resource Impact Indicators (RIIs) [6] is based on the LCIA phases of the ISO 14042 standard [10]. The RII value that is assigned to a resource group follows the precautionary principle [11]. Thereby, the impact pathway of a LCI constituent (see Fig. 1) that contributes to a RII value for any of the resource groups to which it contributes, is taken into account. Furthermore, the summation of the LCI contributions for a resource group is assigned as

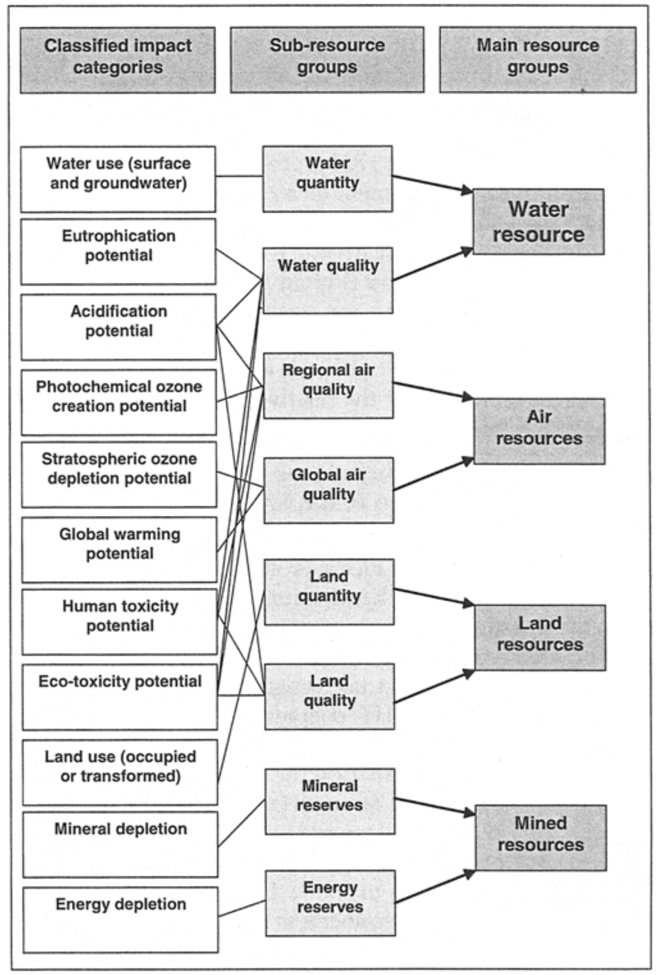

Fig. 1: Proposed RII framework for a South African LCIA procedure [6]

the RII for that resource group [6]. The RII values are calculated according to the general equation (**Eq. 1**):

$$RII_G = \sum_{C} \sum_{X} Q_X \cdot C_C \cdot N_C \cdot S_C \quad (1)$$

Where

RII_G = Resource Impact Indicator calculated for a main resource group through the summation of all impact pathways of LCI constituents on the resource group

Q_X = Quantity of LCI constituent X released to or abstraction from a resource group

C_C = Characterisation factor for an impact category C (of constituent X) within the pathway

N_C = Normalisation factor for the impact category based on the ambient environmental quantity and quality objectives, i.e. the inverse of the target state of the impact category

And; $S_C = \frac{C_S}{T_S}$ = Significance (or relative importance) of the impact category based on the distance-to-target method, i.e. current ambient state (C_S) divided by the target ambient state (T_S)

The calculation of the RIIs therefore follows the procedure stipulated for the Swiss Ecopoints method [12]. However, the subjective normalisation and distance-to-target weighting factors are based on ambient environmental values, rather than emission and resource consumption values of society as a baseline. Thereby, the RII procedure considers the South African natural environment as a reference system and addresses the lack of available (emission and resource consumption) data in South Africa. It must be noted that the distance-to-target method if often not recognised as a true weighting procedure, but an extended normalisation step that does not necessarily reflect the importance of the impact categories to society [13]. However, the method is applied as an indication of the relative importance of the different midpoint categories to the main resource groups.

As has been stipulated before, the characterisation factors are based on those given in the CML procedure, with the following two exceptions:

- No characterisation factor is introduced for the water use category, i.e. the kg of water extracted from natural reserves (surface and groundwater) is taken as such.
- The characterisation factor (land quantity and quality impacts) for the land use category is determined from the Land Use Type (LUT) degradation severities compared to naturally reserved areas, as are shown in **Table 1** [6,14]. The severity of degradation for specific Land Use Types (LUTs) is a reflection of many factors that are associated with the LUTs, e.g. water and wind erosion, salinisation, acidification and other types of soil pollution [6,14,15]. However, the values in **Table 1** are primarily obtained from the perceived judgements in different regions of South Africa of the soil erosion associated with specific LUTs [14]. These judgements have been aggregated for the whole country [6]. Table 1 further compares the erosion factors with the Naturalness Degradation Potential (NDP) factors that have been published for different LUTs [16].

Due to the diversity in the South African natural eco-systems, the current and target states that are required for the different environmental categories of Fig. 1 must be defined for specific regions from a South African perspective [3]. Using the South African region-specific values, more accurate RIIs can be determined for the water, air, and land resource groups.

2.3 Current and target state values for South African Life Cycle Assessment (SALCA) regions

South Africa has been subdivided by grouping the 22 primary water catchments into larger regions that maximise the inclusion of the 18 eco-regions and 68 vegetation types [3,6]. The grouped regions, termed South African Life Cycle Assessment (SALCA) Regions, whereby an improved assessment of life cycle impacts can be performed, are shown in **Fig. 2** [3]. The SALCA Regions more accurately signify the region-specific water and land impacts associated with the South African manufacturing sector (in LCAs), without being too site-specific as is required by, for example, an Environmental Impact Assessment (EIA) [6]. Major metropolitan areas and industrial activities (with associated regional air pollution impacts) are also generally located within the SALCA Regions. However, global air impacts are not allocated to any one of the SALCA Regions specifically. The current state of the ambient environment for these SALCA Regions (in terms of the environmental resources and categories of Fig. 1), as well as the ambient environmental quality or target objectives that have been proposed as a possi-

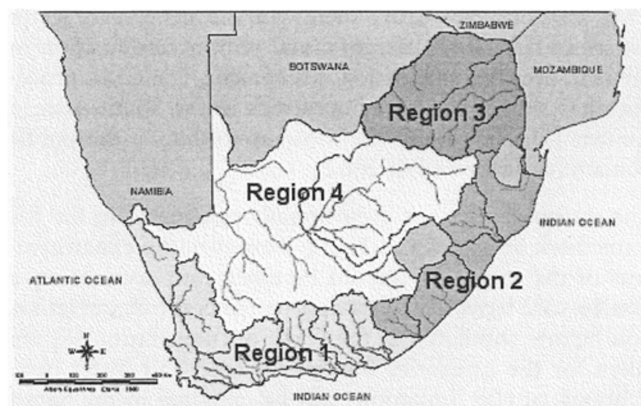

Fig. 2: SALCA Regions grouped from primary water catchments [3]

Table 1: Applied land use type (LUT) degradation severities as characterisation factors [6,14]

Land Use Type (LUT)	Land degradation (erosion) severity value[a]	Naturalness Degradation Potential (NDP) values [16][b]	Comments
Natural	1	0.20	As a benchmark, natural rates of erosion of between 0.02 and 0.75 tonnes per hectare
Near-natural	1.75	0.50	Average taken for non-commercial (communal) croplands and veld grazing in South Africa
Intensively cultivated	1.3	0.70	Average taken for commercial croplands and veld grazing
Moderately urbanised	1.8	0.85	Average value for communal districts of South Africa
Extremely urbanised	0.9	0.95	Average value for commercial districts of South Africa
Severely degraded	2.0	0.95	Maximum documented degradation severity for South Africa (KwaZulu-Natal province)

[a] Occupation: $m^2 \cdot a$ naturally degraded; Transformation: m^2 change in natural degradation
[b] Average values for closely-associated LUTs

Table 2: Current and target values for the classified categories and SALCA Regions [6]

Midpoint category and resource group impact	Measurement units	Ambient annual values	SALCA Region 1	SALCA Region 2	SALCA Region 3	SALCA Region 4
Water use (ground and surface water reserves) **(WU – water resources)**	kg of available reserves	**Current [t]**	1694×10^6	6598×10^6	2407×10^6	2562×10^6
		Target [t]	18×10^6	1123×10^6	1184×10^6	550×10^6
Eutrophication potential **(EP – water resources)**	kg PO_4^{3-} equivalence	**Current [t]**	462.5	1346.2	740.0	1560.6
		Target [t]	69.4	201.9	111.0	117.1
Acidification potential **(AP – air resources)**	kg SO_2 equivalence	**Current [kg]**	306.7	560.2	636.7	573.2
		Target [kg]	233.5	550.7	646.4	521.7
Acidification potential **(AP – water resources)**	kg H_2SO_4 equivalence	**Current [kg]**	5692.6	5239.7	3626.0	2412.5
		Target [kg][b]	7166.5	21108.4	11603.2	12235.1
Acidification potential[a] **(AP – land resources)**	kg H_2SO_4 equivalence	**Current [kg]**	5692.6	5239.7	3626.0	2412.5
		Target [kg][b]	7166.5	21108.4	11603.2	12235.1
Ozone creation potential **(OCP – air resources)**	kg O_3 formed	**Current [kg]**	466.2	1064.3	1209.7	1089.2
		Target [kg][b]	1167.3	2753.5	3232.1	2608.5
Ozone depletion potential **(ODP – air resources)**	kg CFC-11 equivalence	**Current [t]**	3754.8	3377.7	3405.0	9659.7
		Target [t]	2346.8	2117.9	2135.1	6057.0
Global warming potential **(GWP – air resources)**	kg CO_2 equivalence	**Current [Mt]**	1668.7	1505.9	1518.0	4306.5
		Target [Mt]	1600.5	1444.4	1456.1	4130.9
Human toxicity potential **(HTP – air resources)**	kg Pb equivalence	**Current [t]**	3.7	9.8	9.2	8.3
		Target [t]	2.9	6.9	8.1	6.5
Human toxicity potential **(HTP – water resources)**	kg Pb equivalence	**Current [kg]**	245125	242316	436600	257499
		Target [kg]	925	2692.4	1480	1560.6
Human toxicity potential **(HTP – land resources)**	kg Pb equivalence	**Current [t]**	5750	5189	5231	14840
		Target [t]	2168	1957	1973	5597
Aquatic toxicity potential **(ATP – water resources)**	kg Pb equivalence	**Current [kg]**	245125	242316	436600	257499
		Target [kg]	925	2692.4	1480	1560.6
Terrestrial toxicity potential **(TTP – land resources)**	kg Pb equivalence	**Current [t]**	5750	5189	5231	14840
		Target [t]	2168	1957	1973	5597
Occupied land use **(OLU – land resources)**	m^2.a near-natural[c]	**Current [ha]**	1.997×10^7	1.494×10^7	1.556×10^7	5.062×10^7
		Target [ha]	2.015×10^7	1.500×10^7	1.518×10^7	5.152×10^7
Transformed land use **(TLU – land resources)**	m^2 non-natural[d]	**Current [ha]**	3.453×10^6	6.229×10^6	5.889×10^6	9.852×10^6
		Target [ha]	3.279×10^6	6.170×10^6	6.270×10^6	8.953×10^6
Mineral depletion **(MD – mined resources)**	kg Pt equivalence	**Current [Mt]**	35529	35529	35529	35529
		Target [Mt]	16025	16025	16025	16025
Energy depletion **(ED – mined resources)**	kg coal equivalence	**Current [Mt]**	51813	51813	51813	51813
		Target [Mt]	24171	24171	24171	24171

[a] Values for land resources are currently considered equal to those of water resources in South Africa in order to preserve ecosystem quality
[b] Target values reflect the capacity of the natural environment to sustain further burdens
[c] Area conserved in a pristine or near-pristine state of land degradation severity
[d] Area transformed from a pristine or near-pristine state to another land use type degradation severity

ble alternative normalisation procedure [17,18] are shown in **Table 2** [6]. The values of Table 2 are based on the following assumptions and calculations [6]:

- Current and target water quantities are determined from available and projected water balances (based on maximum surface and groundwater yields, human and ecosystem consumption, and the transfer of water reserves) in the stipulated SALCA Regions [19,20].
- Water quality parameters are those concentrations measured at a national level in the different regions [21] and for which minimum values are specified in terms of water quality guidelines for aquatic ecosystems availability or domestic use [22,23], i.e. for the protection of ecosystem quality and human health. For the conversion of concentration values to ambient mass levels, the available and projected water balance volumes are utilized.

- Regional air quality parameters are those concentrations recorded in the vicinity of industrial activities and metropolitan areas [19,24,25,26]. Target values are again defined from concentration values specified for the protection of ecosystem quality and human health [27]. Mass values are calculated from an assumed height of mixing above industrial and metropolitan areas in the SALCA Regions.
- For global air contributions, current measurements [19] and international target concentrations [28,29] are taken into account. These values are assumed equal for all the SALCA Regions.
- Land quantity values incorporate the current areas of all vegetation types in South Africa that are conserved in a pristine state (or a natural severity of degradation) [30], and the international (target) objective of 10% naturally conserved for all vegetation types [31].
- Land quality is already considered in the severity of degradation of land occupation or transformation (see section 2.2). Although the severity of degradation is a reflection of many factors [14,15], additional ambient measured and target values are also introduced for metallic soil pollutants [32].
- Mined abiotic resource values are based on the current and projected mineral and energy reserves that are extensively documented at national level for South Africa [33,34]. These values are therefore not region specific.

The LCIA calculation procedure of Eq. 1, together with the values in Table 2 and incorporated characterisation factors [8,35], can be applied to calculate Resource Impact Indicators (RIIs) for the resource groups.

2.4 Environmental Performance Indicator (EPI) based on the RII baseline calculation approach

The environmental performance of one system (product, process or service) can be evaluated against another known (baseline) system through an Environmental Performance Indicator (EPI). The EPI incorporates a simple ranking value procedure, which has been suggested for project and technology evaluation purposes [36], together with average weighting values that have been determined from the perspectives of South African manufacturing industries and the national government (total value of 1) [37]:

- Water resources – **0.47**
- Air resources – **0.12**
- Land resources – **0.20**
- Mined abiotic resources – **0.21**

Weighting values from the national government's perspective were calculated from the percentage distribution of the part of the total annual budget, which is allocated for environmental issues [37, 38]. For the purpose of determining the weights that are placed on the environmental resource groups by the manufacturing industries, a survey was circulated within two sectors [37]: the automotive supply chain (first, second and third tiers) and process manufacturing industries. A total of 56 companies participated in the survey. The survey was based on the Analytical Hierarch Process (AHP), which is a known Multi Criteria Decision Analysis (MCDA) procedure [39]. The AHP procedure required a pair wise (ration) comparison of the environmental resource groups by members of industry at managing and financial director level [37]. The AHP has been applied before in LCIA methodologies to translate multiple criteria results into a single score [40,41].

The simple ranking value procedure of the proposed EPI approach assigns a qualitative impact value of 1, 0, and –1 to the resource groups, based on the RII performance of a system compared to the baseline. An overall Environmental Performance Resource Impact Indicator (EPRII) for a system is calculated by multiplying the assigned ranking values of the resource groups with the subjective weighting values. A positive summed value of the multiplied results indicates that the evaluated system has a better overall environmental performance compared to the reference system.

3 South African Resource Impact Indicators (RII) for the Wool Case Study

3.1 Wool production case study

The proposed RII procedure is demonstrated with a screening LCA case study, which is a cradle-to-gate life cycle system of the production of 1 kg dyed two-fold wool yarn in South Africa. The life cycle system is divided into two primary processes and a number of sub-processes and auxiliary processes such as transportation [1]:

- Sheep farming and the associated management thereof to ensure profitability, including grazing management, liquid and nutritional supplementation, disease control, shearing and classing of wool fleece.
- The industrial production of wool associated with transforming the natural fibres into yarn for subsequent weaving of wool fabric, and includes the sub-processes of scouring and carbonising, top making, shrink-resist treatment, spinning and dyeing.

The life cycle system and the most important constituents that describe the interaction between the unit processes included in the life cycle system and nature have been documented [1]. The LCI profile can be used for LCIA calculations and analyses [42].

The LCI system of the wool case study is primarily concentrated in SALCA Region 1 of South Africa [1]. Electricity generation is the only auxiliary process that functions outside this region (SALCA Region 3). However, in order to simplify the case study, the LCI profile is applied to SALCA Region 1 solely and the RIIs calculated accordingly with Eq. 1. The results are shown in **Table 3**. The RII procedure indicates the impacts on water resources to be the most important, followed by land resources (factor of 40). The impacts on air and mined abiotic resources are indicated to be of minor importance.

If the LCI system were located in one of the other SALCA Regions, a calculated RII would reflect the actual ambient environmental state in that region. **Fig. 3** shows the relative

Table 3: RII values calculated for the wool LCI in SALCA Region 1 only

Category		Characterisation value	Normalisation value	Resource group	RII
WU	– kg available reserves	5.194×10^{2}	2.044×10^{1}	**Water**	2.053×10^{1}
EP	– kg PO_4^{3-} equivalence	1.048×10^{-3}	1.006×10^{-7}		
AP	– kg H_2SO_4 equivalence	9.107×10^{-2}	1.009×10^{-5}		
HTP	– kg Pb equivalence	2.457×10^{-1}	7.040×10^{-2}		
ATP	– kg Pb equivalence	3.913×10^{-2}	1.121×10^{-2}		
AP	– kg SO_2 equivalence	5.919×10^{-2}	3.330×10^{-4}	**Air**	3.370×10^{-4}
OCP	– kg O_3 equivalence	3.530×10^{-3}	1.208×10^{-6}		
ODP	– kg CFC-11 equivalence	4.272×10^{-8}	2.912×10^{-14}		
GWP	– kg CO_2 equivalence	1.134×10^{1}	7.386×10^{-12}		
HTP	– kg Pb equivalence	6.458×10^{-3}	2.841×10^{-6}		
AP	– kg H_2SO_4 equivalence	9.107×10^{-2}	1.009×10^{-5}	**Land**	4.936×10^{-1}
HTP	– kg Pb equivalence	9.183×10^{-4}	1.123×10^{-9}		
TTP	– kg Pb equivalence	3.357×10^{-4}	4.106×10^{-10}		
OLU	– m^2.a near-natural	1.333×10^{4}	4.935×10^{-1}		
TLU	– m^2 non-natural	0	0		
MD	– kg Pt equivalence	8.164×10^{-8}	4.584×10^{-8}	**Mined abiotic**	1.735×10^{-5}
ED	– kg coal equivalence	4.821	1.735×10^{-5}		

RII values compared to the SALCA Region 1 for the wool case study LCI in the different SALCA Regions and for South Africa as a whole, i.e. taking into account an overall current and target state for environmental resources. Certain LCI constituents would, however, change with respect to the specific regions, e.g. less land would be required per kilogram of wool produced in the farming stage in SALCA Region 2 compared with SALCA Region 1. This shows that not only the LCIA needs to be spatially differentiated, but the LCI as well.

The simple RII results comparison indicates the possibility of a baseline approach where the overall environmental performance of one system is evaluated against another, using the Environmental Performance Indicator (EPI) approach of section 2.4.

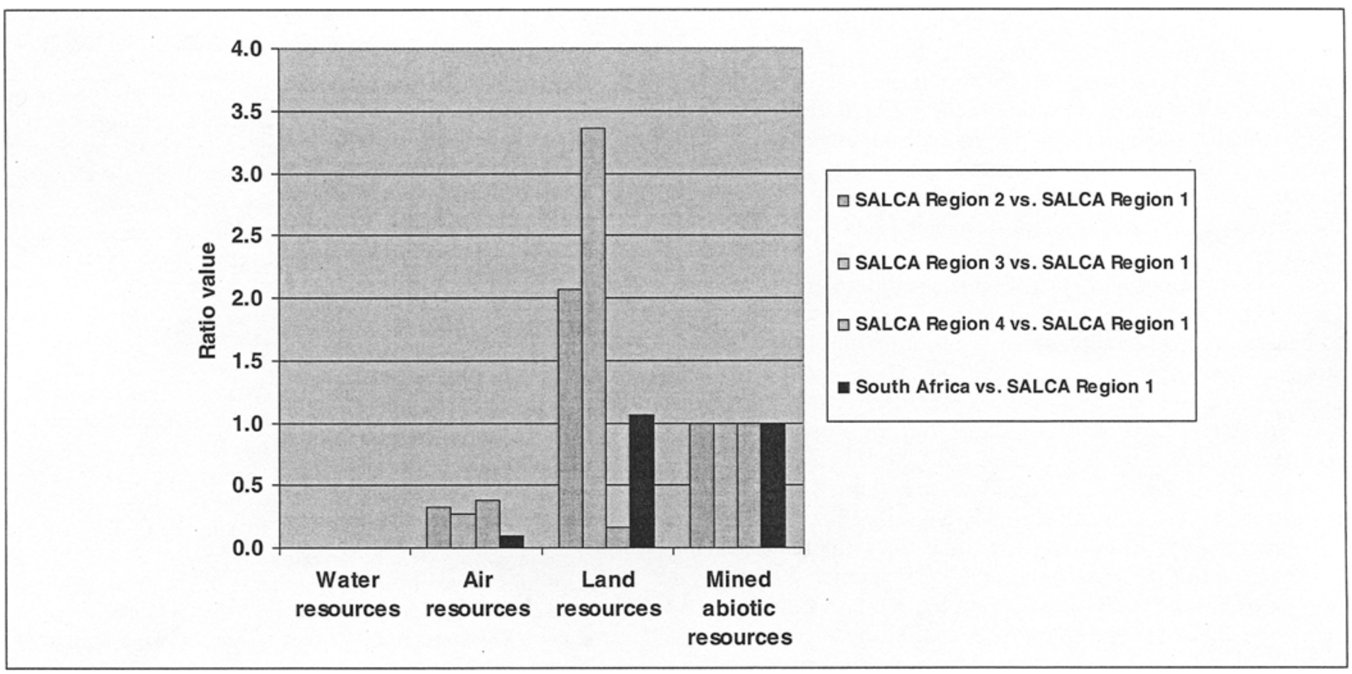

Fig. 3: Calculated RII values for the SALCA Regions and for the overall South African environment compared to the SALCA Region 1 baseline (ratio values for water resources are less than 0.005)

Table 4: Assigned ranked values and calculated EPRIIs for the wool LCI systems in different eco-regions

Resource group	Ranked value			
	SALCA Region 2 vs. Region 1	SALCA Region 3 vs. Region 1	SALCA Region 4 vs. Region 1	South Africa vs. SALCA Region 1
Water resources	1	1	1	1
Air resources	1	1	1	1
Land resources	−1	−1	1	−1
Mined abiotic resources	0	0	0	0
EPRII	**0.39**	**0.39**	**0.79**	**0.39**

3.2 Environmental Performance Resource Impact Indicators (EPRIIs) for the wool case study

For the wool case study the LCIs of the systems are assumed to be similar, whilst the different systems operate in specific eco-regions. The results of the EPRII approach (of section 2.4) with the wool system in SALCA Region 1 as the baseline (see Fig. 3) are shown in **Table 4**. A value of −1 is assigned where the ratio of RII values are higher than 1, and a value of 1 where the RII value for SALCA Region 1 is higher. A value of 0 depicts that there is no difference between the evaluated system and the baseline (or reference) system.

For the wool case study, the calculated EPRII values show that a wool LCI system, similar to the best practices in SALCA Region 1, placed in any other SALCA Region would perform better. The best environmental performance is calculated in SALCA Region 4. Also, where the ambient environmental state is considered at regional level, the environmental performance may be worse (SALCA Region 1) compared to the whole of South Africa as one region.

4 Conclusions

A Life Cycle Impact Assessment (LCIA) procedure has been proposed, which focuses on four environmental resource groups as Areas of Protection (AoP): Water, Air, Land and Mined Abiotic Resources. Protection of the resource groups ensures that the ambient environment is adequate to sustain human health and ecosystem quality without adverse effects, except for mined abiotic resources, which is necessary for human welfare. Based on the distance-to-target approach, the current and target ambient state levels define the importance of conventional midpoint categories that contribute to the total impact of a system on the resource groups. The LCIA framework allows for additional midpoint categories to be introduced at a later stage, e.g. salinity impact categories for water and land resources [43]. The precautionary principle is followed to calculate a Resource Impact Indicator (RII) for a LCI system for each resource group. An Environmental Performance Indicator (EPI) approach is further introduced, to compare the performance of one LCI system to another in terms of calculated RIIs. Subjective weighting values for the resource groups are used to calculate an overall single score or Environmental Performance Resource Impact Indicator (EPRII). Applying the RII and EPRII procedure to the wool screening LCA case study shows that a spatially differentiated approach influences the results of the LCIA and also affects the quantification of LCI constituents, especially with respect to land and water usage.

4.1 Way forward

The application of the proposed EPRII procedure will be investigated further for Life Cycle Management purposes. Of specific interest is the evaluation of new technologies at governmental level, e.g. for Clean Development Mechanism (CDM) approval purposes [44], and company performances for supply chain management. In terms of the latter, the environmental performance per economic input is determined for companies supplying components and materials to larger manufacturing facilities. Within the developing country context, the limited LCI information that is obtainable from supplying companies is of particular importance. Where LCI data is inadequate in the supply chain, an adaptation of the RII and EPRII approach will be proposed and demonstrated for a typical South African automotive supply chain.

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